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AN BIVARIATE MODEL OF INTELLECTUAL EXCEPTIONALITY: AN ANALYSIS OF INDIVIDUAL DIFFERENCES IN INFORMATION ENCODING PROCESS

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An analysis of individual differences in information encoding process

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ABSTRACT: Mental retardation, learning disabilities and intellectual giftedness have long been separated as different fields. In the past decade research findings suggested a continuity within the general intelligence spectrum which place the gifted on one extreme and the retarded on the other; as well as a two dimensional taxonomy of intellectual exceptionalities. Based on psychological studies of human abilities and human information encoding processing, and the biographical evidence of eminent people and specific giftedness of savants, a bivariate model of intellectual exceptionality is proposed in this study. This model links all intellectual exceptionalities together with normal people, and gives a clear picture about the location of each specific group at the human information encoding level, and suggests that use of a bivariate distribution to roughly estimate the population of each specific group.

INTRODUCTION

Mental retardation, learning disabilities and intellectual giftedness have long been separated as different fields. The three fields have their own journals, researchers, theories, and research problems. In the past decade this picture has started to change. Zigler and Farber (1985) compared intellectual giftedness and mental retardation and tried to place them as two extremes in the same field. Davidson (1986) studied giftedness on insight problem solving, and suggested that three metacognitive skills, selective encoding, selective combination and selective comparison are important factors in distinguishing highly intelligent from less intelligent individuals. Geary and Brown (1991) compared the performances of mathematically gifted, normal, and disabled third and fourth grade children on 40 simple addition problems. Results showed that the gifted group chose the most mature strategies, followed by the normal and disabled groups. The authors suggested that the maturity of organization of basic facts in long-term memory was a single dimension that

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spanned group differences in problem mastery. Jackson and Butterfield (1986), and Borkowski and Kurtz (1987) also sought to bring together the field of retardation and giftedness. Research findings such as these seems suggest a continuity within the general intelligence spectrum which place the gifted on one extreme and the retarded on the other extreme.

Other evidence from research on specific giftedness of savants, such as Eddie (Miller, 1989), and Nadia (Gardner, 1982) suggested that without metacognition and flexible strategies, one can be an gifted in a narrow area. Biographical information on eminent people, such as Einstein, Faraday, Churchill, Da Vinci and many others who exhibited exceptional spatial abilities, but also had verbal learning problems in their early school years (Shepard, 1978; West, 1991), further supports a dimension of specific giftedness.

Sternberg (1987) proposed a two dimensional taxonomy of intellectual exceptionalities, as shown in Table 1. He used the triarchic theory of intelligence to describe the nature of the differences between general and specific giftedness,

Table 1 Two dimensional taxonomy of intellectual exceptionalities

Breadth of Intellectual Exceptionality	Level of Intellectual Exceptionality	
	High	Low
General	General Giftedness	Mental Retardation
Specific	Specific Giftedness	Learning Disability

and compare these differences with which of learning disabled and mental retarded children. In this way, he formed an unified theory of intellectual exceptionality. The dimension of general intellectual exeptionality emphasizes a balanced ability pattern varied from low to high, whereas the specific intellectual exceptionality dimension suggests several uneven ability patterns with one ability higher and the other lower.

However, this taxonomy did not specifies the kinds of specific intellectual exceptionality. After reviewed psychological theories of human information encoding processing and theories of human abilities, I try to introduce a bivariate model of intellectual exceptionalities at the

information encoding level to link all kinds of intellectual exceptionalities together with normal people, and gives a clear picture about the location of each specific group.

Theories of Information Encoding

Information encoding is the first step of human information processing. Knowledge and higher level problem solving skills, such as strategies, schemata, are all built on these elementary abilities. There are at least three theories about information encoding: Just and Carpenter's (1990) working memory capacity theory, Baddeley's (1986) tripartite system theory, and Anderson's (1983) multiple code theory. However, the conception of information encoding in all three theories goes beyond the traditional conception of memory as information storage, to memory as information processing.

Working memory capacity theory presents an integration of the information storage and processing functions of working memory in language comprehension (Just & Carpenter, 1992). In this theory both storage and processing are fueled by the same commodity: activation. The capacity of working memory can be expressed as the maximum amount of activation available to support either of these functions. Each representational element of working memory has an associated activation level. During comprehension, information becomes activated by being encoded from written or spoken text, generated by a computation, or retrieved from long-term memory. As long as an element's activation level is above some minimum threshold value, that element is considered part of working memory, and consequently, it is available to be operated on by various processes. If the intervening computational activities exceed the capacity of the system, then, some elements will be deleted by changing their activation level. In the extreme, these elements are deactivated entirely - for example, forgotten. The processes underlying comprehension and storage are assumed to occur in parallel within working memory capacity. While encoding words and retrieving representation of the words, the reader or listener can also be calculating other syntactic and semantic features of the sentence. The tradeoff between storage and processing occurs under an allocation scheme that takes effect when the activation maximum is about to be exceeded. When the task demands exceed the available resource both storage and computations are degraded (Just & Carpenter, 1992).

According to this theory, individuals are assumed to vary in the amount of activation they have available for meeting the computational and storage demands. Some people may have larger capacity than others. People with a larger working memory capacity may be able to

draw on a larger supply of resources. Several experiments (Daneman & Carpenter, 1980, 1983; Kyllonen & Christal, 1992) studied the relationship between general reasoning ability and working memory capacity, and found a consistently high correlation coefficient between them.

The tripartite theory of working memory was introduced by Baddeley and his colleagues (1986, 1992). This theory suggested a two level working memory system with a central executive and two slave systems: the phonological loop and visuo-spatial sketch pad. The phonological loop has two functions: it can maintain information within the phonological store by subvocal repetition, and can take visually presented material such as words or namable pictures and register them in the phonological store by subvocalization. Baddeley (1992) drew from a variety of research results to support the existence of the phonological encoding system. The acoustic similarity effect (Baddeley, 1966; Conrad, 1964; Conrad & Hull, 1964; Wickelgren, 1965), the articulatory suppression effect (Estes, 1973; Peterson & Johnson, 1971; Levy, 1971; Murray, 1965, 1967, 1968), the word-length effect (Baddeley, Thomson, & Buchanan, 1975), and the irrelevant speech effect (Colle, 1980) are evidence can be found only in the phonological processing.

There also appears to be good evidence for the existence of the second slave system: a temporary visuo-spatial store that is capable of retaining and manipulating images. First, images are susceptible to disruption by the requirement of performing a visuo-spatial task, such as tracking a spot of light moving on a screen, by certain type of eye movements, or by the presentation of irrelevant visual material during learning. Second, research findings (Baddeley, 1986) suggested that the eye-movement seems play some role in this type of memory. Baddeley (1986) pointed out both the phonological loop and the visuo-spatial sketch pad appear to take advantage of an essentially passive perceptual input store. In both cases, the problem of coping with rapid decay from the store appears to have been solved by an active control process based on a response system, articulation in the case of the phonological loop, and eye movements in the case of the visuo-spatial sketch pad. These allow the transformation of a passive perceptual store into active memory system that enable the organism to take information out of the relevant input store and to feed it back.

The function of central executive is clearly specified in tripartite theory as an attention system (Baddeley, 1986; Gathercole, & Baddeley, 1990). One proposed role for the central executive is that of coordinating information from two slave system. Just and Carpenter(1992) claimed that processing language, the central executive corresponds

approximately to capacity theory. Research in this area has shown two phenomena. One is limited capacity (Seibel, 1963, cited in Baddeley, 1986), the other is trading relationship between the storage and processing which suggested that the two functions were drawing on a common pool of resources, the general working memory, or central executive of working memory (Baddeley & Hitch, 1974; Baddeley, 1986).

Anderson's (1983) multiple code theory[1] is similar to Baddeley's tripartite theory. It hypothesizes a two level theory of mental representation. At the low level, or the perceptual level there may be several perception based memory codes. However, the two dominant ones are a linear order code (or temporal string code), and a spatial image code. The reason for the different perception-base representation codes is that these processes treat different information differently. An important use of string code is to encode word or morpheme order in language, whereas the important use of image code is to represent configural information. The two perceptual level codes have their own properties. Santa (1977) has nicely illustrated the difference between spatial and string representations. The high level representation is defined by an abstract or propositional code that preserves information about meaning of sentences and pictures. Meaningful propositions are capable of entering into hierarchical proposition network as a unit within another proposition, and some set of propositions cohere together to form schema, which is the way to encode regularities. Thus, the function of whole encoding system is to select and organize raw information for further assimilating and accommodating it into person's knowledge structure.

Taken together, the three theories depict an information encoding system that has two levels and a two dimensional structure. At the perceptual level, there are two main types of representation: the phonological code and the image code. They are fueled by a common pool, attentional capacity that is regulated by a central executive. Individual differences in total working memory capacity are highly correlated with general reasoning ability.

The two main information encoding abilities can be also found in the research on human cognitive abilities. The literature is summarized in the next section.

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1. Multiple code theory is a part of Anderson's (1983) ACT model which stands for Adaptive Control of Thought.

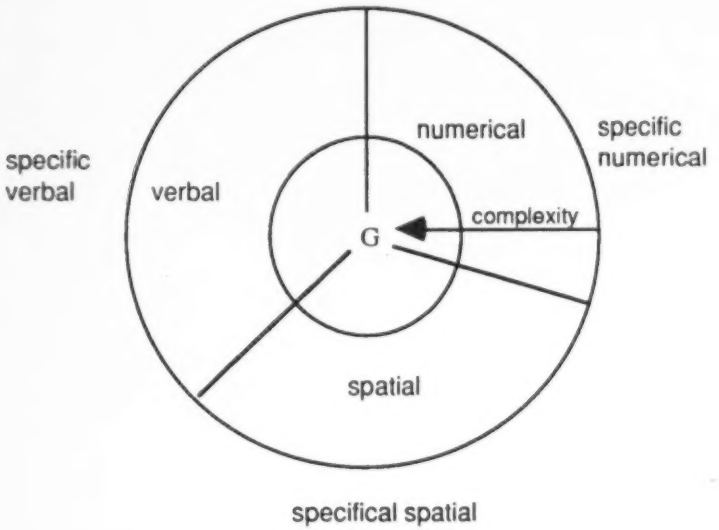
Nature of Human Abilities

There have been many debates on the nature of human abilities during a century of psychological study. The central controversy is about the structure of human abilities. In 1904, British psychologist, Spearman, introduced an unifactor model. This model maintained that all intellectual activities share a single common factor, called the "general factor" or G. In addition, the model postulated numerous specifics, or S factor, each being strictly specific to a single activity (Anastasi, 1986). In 1930, Thurstone developed multiple factor analysis method, and proposed multiple-factor theory. The factors he found using his method were: Verbal Comprehension, Word Fluency, Number, Space, Associative Memory, Perceptual Speed, and Induction (or reasoning). However, the number of independent factors grew from Thurstone's seven PMA, to Guilford's (1967) 120 intellects in his facet model. These factors were defined by a particular combination of content, cognitive operation, and product.

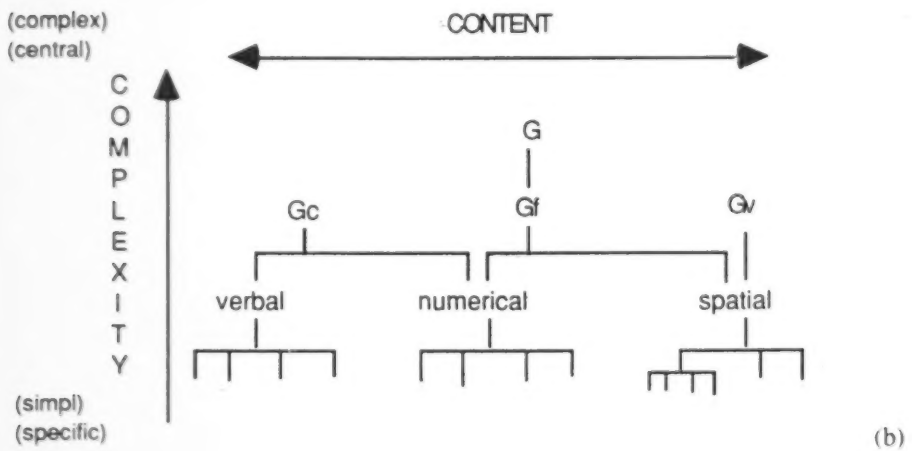
The hierarchical model of ability structure was proposed by British psychologists Burt (1940) and Vernon (1950) as well as American psychologists Humphreys (1962), Cattell (1971), and Horn (1976). At the top of hierarchical model there is the general ability G which is a broad general factor that accounts for performance in a great variety of intellectual tasks. At the second level beneath G, Cattell (1971) and Horn (1976) identified crystallized ability (Gc) with verbal comprehension and knowledge emphasis, fluid ability (Gf) with nonverbal and analytic reasoning emphasis, and visualization ability (Gv) with figural and spatial emphasis in their hierarchical model (Marshalek, Lohman, and Snow, 1983). These broad group factors at the second level could be further subdivided into narrower, and more test-specific factors at the next lower level as shown in Figure 1, (b). The hierarchical model has two features. First, tests that load highly on the general factor in this model tend to be more complex tests. Second, the horizontal spectrum spreads tests out among group factors at various hierarchical levels. Thus, this model is actually a two dimensional continuum. The horizontal dimension at the intermediate level of the model can be expressed as the content dimension, whereas the vertical dimension can be called the complexity dimension which means an ordering of ability tests along this dimension is done according to their correlation with G (Marshalek, Lohman, and Snow, 1983).

Finally, the Israeli psychologist, Guttman (1954), proposed a radex model (Marshalek, Lohman, and Snow, 1983). He used a multidimensional scaling technique to generate a circular map of the ability space with three content-based slices: verbal, numerical, and

spatial (See Figure 1, a). In his multidimensional scaling technique, tests are represented as points in a two dimensional space; the higher the correlation between the tests the greater their relative proximity in the space. In this model the dimension along the radius is also a complexity dimension: more complex tests which highly correlate with G are located in more central regions; more specific test which lower correlate with G are located in more peripheral area of the radex.



(a)



(b)

Figure 1. Schematic representation of the radex(a) and hierarchical factor(b) models.

Data from re-analysis of Thurstone's PMA study have most clearly confirmed the Space (spatial), Number (numerical), Verbal Meaning, and Memory factors. The identities of Perceptual same three factors: verbal (semantic), spatial (figural), and numerical (symbolic) in Guilford's model. These three factors capture more variance than any other primary factors in many test score analyses. Thus, we can say in the ability domain, the most consistently obtained group factors which defined by the test content are verbal, spatial, and numerical. Each of them is itself a hierarchical organization of its abilities.

The verbal-spatial split is the most consistent dichotomy in differential psychology literature. Both abilities hold a prominent place in theories of human cognition and in all models of human abilities, as mentioned above. Factor-analytic studies of spatial abilities show a broad array of spatial factors, that may be roughly organized hierarchically (Lohman, 1979). A complex spatial visualization factor (Vz, or Gv) appears near the top of this hierarchy. It is usually defined by complex spatial tests such as Form Board test, Paper Folding test, and Surface Development test. It is the difficult to separate this factor from fluid-analytic reasoning abilities. The Spatial Orientation (SO) factor can sometime be distinguished from Vz factor, and appeared to involve the ability to imagine how an array would appear from different perspective, and then to make a judgment from that imaged perspective. A Speeded Rotations (SR) factor emerges if two or more simple, highly speeded rotation tasks are included in the test battery. Other spatial factors include Flexibility of Closure, Speed of Closure, Perceptual Speed, Visual Memory, Serial Integration, etc.

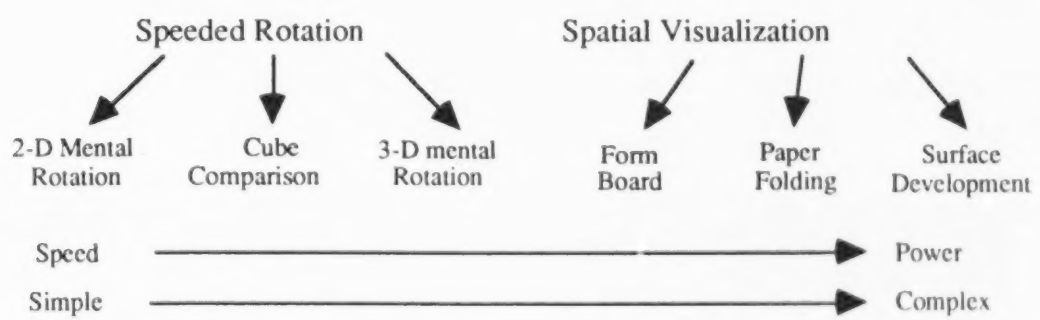


Figure 2. Simplified representation of speeded-rotation and spatial visualization factors, their tasks and performance dimensions.

The differences between speeded-rotation and spatial-visualization seem reflect two complementary dimensions of performance (Lohman, 1979). One is complexity dimension. The other is speed-power dimension. Pellegrino and Kail (1982) presented these dimensions as shown in Figure 2.

Process analyses have been performed on several Vz tasks (Alderton, & Pellegrino, 1984; Kyllonen, Lohman, & Snow, 1984; Kyllonen, Lohman, & Woltz, 1984; Lohman, 1979, 1988), and revealed that most Vz tests require subjects to perform several different operations or multiple executions of the same operation, and the requiring a subject to execute several transformations places strong demands on the quality of the mental image (Lohman, 1988). Pellegrino and Kail (1982) summarize several studies in which the mental rotation tasks were administered after some PMA space tasks. Results form both simple and complex rotation tasks and spatial-visualization tasks are that the speed of encoding and comparison was significantly related to all three kinds of spatial skills, and the accuracy of encoding and comparison was only significantly related to more complex tasks. Thus they concluded that the spatial ability may associate with the ability to estimate sufficiently precise and stable internal representation of unfamiliar visual stimuli that can be subsequently transformed or operated with minimal information loss. In a processing study of spatial ability, Carpenter and Just (1986) find some characteristics of high spatial ability subjects. First, they seem to be easier at encoding spatial information, and do so more accurately, and in more detail. Second, they are better at generating, maintaining, and coordinating information during spatial transformation. So the researchers suggest that high spatial ability subjects may have better spatial "vocabulary", that is, they have chunks that allow for more efficient encoding and construction and more accurate retrieval of spatial information. After ten years' study on spatial abilities, Lohman (1988) states his view about spatial ability as follows: "Our experiments with rotation tasks, synthesis tasks, and matching tasks suggest individual differences in spatial abilities may be modeled as differences in both image-coded and propositionally coded spatial knowledge and in the general purpose and special purpose procedural knowledge that operates on this declarative knowledge base. The ability to create image-coded memories and perform analog transformations such as rotation and synthesis that operate on such representations are the core of spatial abilities."

A verbal factor was one of the first to be dependably separated from Spearman's (1927) general ability. In the PMA model Thurstone (1938) identified two verbal abilities.

Carroll (1940) showed that at least eight verbal factors, and then Guilford (1967) posited even more verbal abilities in the semantic slice of his facet model.

Cognitive research revealed characteristics of the verbal tasks that show relatively low or high correlations with reasoning tests. The tasks showed lower correlation with reasoning measure usually are simpler, thereby placing a greater premium on speed of response, or emphasize specialized knowledge of linguistic conventions, such as grammar, understanding idioms, and so on, or demand phonological or articuatory processing instead of semantic processing, or require remembering the exact order of letters or sounds. The tasks correlated highly with reasoning measure are the tasks require integration across sentences (such as comprehension), or use relatively abstract words, or require definition, or precise understanding of concepts, or demand increasing inference. Cognitive research has suggested that the difference between the two kinds of verbal tasks may caused by the nature of memory code on which performance is based. As Anderson(1983) hypothesized that the abstract code system preserves meanings, such as propositions, ideas, or adjustment, whereas the perception-base code preserves order information (string code), the configural information, and maybe other special sensory information. General reasoning measure may estimate facility in creating, retaining, and transforming information coded as abstract propositions, whereas specific verbal measure may estimate both how well and how fast one can create, retain, and transfer perception-based codes (Snow, & Lohman, 1989).

The complex verbal task, such as comprehension, composed of many subprocesses, from automatic acts of lexical identification, involuntary phonological or image encoding to the planned strategies people use to extract meaning from lengthy texts. The elementary actions build on each other. There is a build in correlation between performance on lexical-analysis task and on a sentence-analysis task, and between sentence and paragraph comprehension (Hunt, 1985). Individual differences in verbal abilities occur in all these areas. Research on the basic processes, such as lexical analysis and encoding procedure, has found that high-ability reader were distinguished from low-ability readers by their skill at multiple-letter coding, especially when a response must be made to several letters at once (Frederiksen, 1978). Jackson and McClelland (1979) concluded on the basis of a range of cognitive tasks that reading comprehension is dependent on two main factors, general comprehension ability and "speed of accessing over-learned memory codes for visually presented letters". Perfetti's (1985) verbal efficiency theory emphasizes that the word-level processes need to occur with minimal effort, so that working memory can be devoted to comprehension

work. Hunt, Frost, and Lunneborg (1973) have suggested that an important component of reading is the ability of to access a phonological code on the basis of a visual stimulus.

Mathematical abilities differ from verbal and spatial abilities in two ways. One is they are not as strongly differentiated from factor analyses as verbal and spatial abilities, and the other is only two quantitative factors appear with consistency (Snow & Lohman, 1989), namely, numerical facility and quantitative reasoning. It seems that mathematical abilities have not been studied as broadly and deeply as verbal and spatial abilities. Perhaps, it caused by the wide range of its materials. Mathematics means many things. According to the common definition mathematics is a science of space and number, due to the root of geometry and algebra. But now mathematics is clearly seen by more and more mathematicians, as a science of pattern (Steen, 1988). However, math is also concepts, symbols and rules learned in elementary schools. At the beginning, math learning requires repetition, practice and root memory of symbols, concepts, rules, and different combinations of them. Then, from high school on, while studying algebra, geometry, trigonometry, calculus and even more advanced math material , it requires more and more space thinking , visual-based sophistication, and pattern recognition than symbol manipulation.

Both correlational and experimental research has accumulated evidence about mathematical ability. Cognitive studies of computational abilities in children suggest that good computational skills acquisition models seem to be similar to those models from research in reading (McClelland, & Rumelhart, 1981). By third and fourth grade children solve mathematical problems syntactically, namely, by applying memorized rules to the manipulation of symbols (Resnick, 1982). The improvements in mathematical problem solving have been repeatedly linked to advances in conceptual or semantic knowledge (Rilry, Greeno, & Heller, 1983). However the research in math talents has shown that high mathematical ability related to high spatial ability (Benbow, 1990; Benbow, & Minor, 1990). Factor-analytic studies have obtained evidence that spatial ability tests higher correlated with geometry test than arithmetic and algebra (Smith, 1948, 1954.). Kelly (1928) has held that arithmetical ability involves a considerable amount of the verbal factor in pupils of the third grade but not for seventh grade (cited in Smith, 1964). In three-factor space, mathematical ability often falls between verbal and spatial abilities. It could indicate that mathematical reasoning requires both verbal and spatial abilities (Snow & Lohman, 1989).

Taken together, perhaps we could assume that the mathematical abilities vary widely from elementary to advanced levels. At the elementary level mathematical abilities may related highly to the ability in string coding of information, memorizing and manipulating symbols and the strategies of manipulating. At the advanced level it may related mainly to the abilities in image coding, pattern recognition, and visual-based strategies.

The Bivariate Model of Intellectual Exceptionalities

Research on human information encoding processing suggests that two main information encoding abilities are phonological coding ability and image coding ability. The former deals with verbal information, whereas the latter deals with visual and spatial information. Both factor-analytic and cognitive processing studies on human cognitive abilities suggest a hierarchical structure for organizing the complex human abilities. At the top of the structure there is a general ability G. It composes mainly of three factors: verbal, spatial and mathematical. Each of the these abilities is themselves a hierarchical structure also. At the information encoding level, there are also two main information encoding abilities. High spatial ability is related to image and image-proposition coding, and high verbal ability is related to the speed and accuracy of string code of information, especially, the phonological coding on the basis of visual stimuli while reading. Mathematical abilities are different to verbal and spatial abilities. They seem to vary with human growth. For the elementary school students, high math abilities may mean the abilities in string code of information, and manipulation of symbols. For the advanced math problem solvers, the high math abilities may be associated with the abilities in image coding and pattern recognition, which are highly associated with spatial ability.

Since the information encoding abilities are at the elementary level of the ability structure, they are far from general ability G, thus the correlations between them and G should be low. Moreover, the two information encoding abilities deal with different type of information, thus they are more likely to be independent to each other. Since the two types of information encoding ability are fueled from a common pool, the working memory capacity, and each individual has a certain working memory capacity, they are likely to be trade-off to each other within a certain amount of working memory capacity. Based on all these assumptions, I proposed a bivariate model to pull together all kinds of intellectual exceptionalities, together with normal people at the information encoding level. The model is shown in Graph 3.

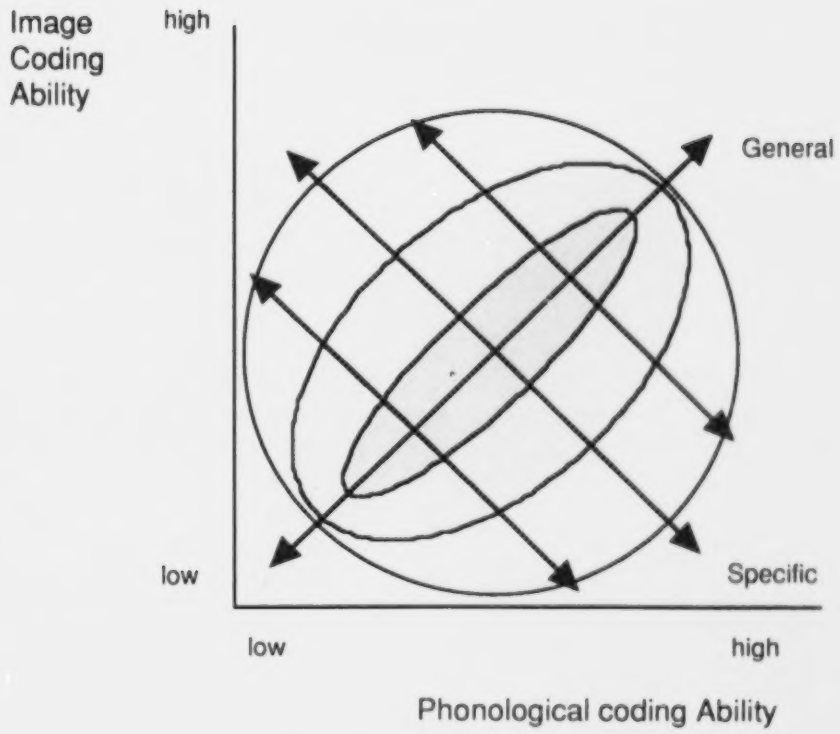


Figure 3. Bivariate model of a hypothetical diversity of human abilities at information encoding level

The large circle in the Figure 3 stands for a population. Perhaps we can say that 99% of the population is enclosed in the cycle. The dimension form low-left corner to the up-right indicates the general ability vary from low to high. The dimension from up-left to low-right indicate the variation of specific abilities. People on the same lines of the specific dimension are assumed to have same general ability, but varied specific abilities: the people on the up-left half have high image coding, but low phonological coding abilities, and the people on the low-right half, just the opposite. There is a trade-off along this dimension. Phonological deficit children with lower general abilities fall in the low-left end of the circle may have low phonological coding abilities and relatively higher image coding ability. However, due to the low working memory capacity the image coding abilities cannot be traded highly. If the high spatial individuals are located on the up-right end of the circle with very high working memory capacity may not have to be a dyslexia to trade for their giftedness.

although they could show an uneven pattern with high image coding ability and relatively lower phonological coding abilities. People in the middle part of this dimension with moderate general abilities, their abilities patterns varied widely. The individuals around the center are assumed to have more balanced ability patterns, whereas the people on the periphery may have very uneven ability patterns. Another variable we need to concern with in this model is perhaps the density of population. We may assume the area within the small ellipse around the center of the circle has highest density. Most people, say around 60% of the whole population, are distributed there. The area between two ellipses has medium density, and the area outside of the large ellipse has low density, say only about 5% of the whole population is scattered there. The gradual reduction of density from center to periphery is continuous. A highest density concentration occurs within the center of this model, and gradually declines as it moves from center to edge. However, there is still 1% of the population which did not lie in the circle. It is possible that the people located there are even more highly exceptional people.

Based on the psychological theories and studies I proposed bivariate model of intellectual exceptionality at information encoding level. The model raises many research questions. The fist question is: is the data from real world fit the model and how the distribution of the two composites looks like. I tried to answer this question in this study.

METHOD

To investigate the relationships between image and phonological coding abilities I need to: (1) select a large standardized sample which can represent a population more precisely, (2) administer a series of tests which measures phonological and spatial image coding abilities. For these reasons, I decided to use Project TALENT public use data, because the sampling strategy, and the research instruments make it well suited to serve my research purpose.

Project TALENT is a large-scale cross-sectional study, which investigated the interests, information, abilities, and backgrounds of more than 400,000 Americans who were in grades 9 to 12 in 1960. The sample was randomly selected according to the type of school (public, parochial, private) and the geographic location. The data I used is the public use file which contains only one percent (4,000 subjects) of the original data. In the spring of 1960, all the TALENT participants were given a two day battery of tests and inventories.

This battery was designed to provide baseline data on the aptitudes and abilities of these individuals, as well as to assess their interests and various personal characteristics. For my research purpose, I am only interested in the cognitive subtests which are related to image and phonological coding abilities.

On the bases of test content descriptions, two language subtests, Disguised Words and Spelling, appear to test phonological coding ability. According to Carroll (1993), the phonetic coding factor usually is defined by tasks in which subjects is required to induce grapheme-phoneme relationships. Disguised Words seems to be this kind test. Disguised Words is designed to measure the ability to form connections between letters and sounds. In this test, a word is represented by certain letters which suggest the sound of the word, for example, "STRAT" for "straight", or "DLA" for "delay". Examinees must then identify the word. The vocabulary level is simple, thus minimizing the impact of vocabulary knowledge. Spelling ability is also similar to phonetic coding. "This association may come about because a phonetic coding ability is in some way basic to good spelling ability" (Carroll, 1993).

There appears to be no measure of pure image coding ability in Project TALENT data file. As discussed above, to solve the problems in spatial ability tests, subjects should execute several transformations, which places strong demands on the quality of the mental image. Therefore the two spatial ability tests: Visualization in Two Dimensions and Visualization in Three Dimensions could be regarded as the indices of image coding ability. The questions in Two Dimensions Visualization test consist of a target diagram followed by five diagrams; the task of the examinee is to determine which of the five diagrams is exactly the same as the target whereas the others are mirror images, through turned around to different positions. This test is likely to load on a speeded rotation factor, which is one of the three major spatial ability factors (Lohman, 1979). The test of Visualization in Three Dimensions measures the ability to visualize how a two dimensional figure would look after it had been folded to make a three-dimensional figure. This ability is more likely to be categorized into Vz or Gv factor. I am interested in these two tests, because they gave information about one's spatial abilities which include spatial image coding ability.

Having selected predictor variables, the raw scores of Disguised Words and Spelling test were composed as phonological coding ability composite, and the two visualization test scores were clustered as a image coding ability composite. The procedure of clustering is: first, convert the raw scores on these tests into Z scores with means equal to 0 and standard deviations equal to 1; then, average the standardized scores of two tests defined as same

factor for each cluster into composite score for each student. Both raw scores of the four tests and two composites were used as independent variables in this study.

To confirm the bivariate model, a scatterplot of the whole sample was created with one dimension as phonological coding ability and the other as the image coding ability. The correlation coefficient, the means and standard deviations of the two composite scores, then, were calculated as well. If normality is true for the distribution of each coding ability, the distribution of the two composites could be bivariate normal. Thus, the next step was testing bivariate hypothesis.

Each composite variable was cut into six parts by its standard deviation, namely, <(-2)SD, (-2)-(1) SD, (-1)-0 SD, 0-1 SD, 1-2 SD, and >2 SD, to make a 6*6 table. I then determined the number of subjects for each cell as its observed frequency. The bivariate normal distribution has its density function (Tatsnoka & Lohnes, 1988):

$$f(x,\ y) = \frac{1}{2p\sqrt{\sigma_{xx}\sigma_{yy}(1 - \rho_{xy}^2)}} \times \exp\left\{ -\frac{1}{2(1-\rho_{xy}^2)}\left[\left(\frac{x-\mu_x}{\sqrt{\sigma_{xx}}}\right)^2 + \left(\frac{y-\mu_y}{\sqrt{\sigma_{yy}}}\right)^2 - 2\rho_{xy}\left(\frac{x-\mu_x}{\sqrt{\sigma_{xx}}}\right)\left(\frac{y-\mu_y}{\sqrt{\sigma_{yy}}}\right)\right]\right\}$$

The means and standard deviations of, and the correlation between the two observed variables were used as estimates of μ_x, μ_y, σ_x, σ_y, and ρ_{xy} to build a bivariate normal distribution. This theoretical bivariate normal distribution were also cut into 6*6 cells by two standard deviations, then integrate each cell to get the probability of the cell (Cij). The formula is:

$$Cij = \int_{x_i}^{x_{i+1}} \int_{y_j}^{y_{j+1}} \frac{1}{2p\sqrt{\sigma_{xx}\sigma_{yy}(1 - r_{xy}^2)}} \times \exp\left\{ -\frac{1}{2(1-\rho_{xy}^2)}\left[\left(\frac{x-\mu_x}{\sqrt{\sigma_{xx}}}\right)^2 + \left(\frac{y-\mu_y}{\sqrt{\sigma_{yy}}}\right)^2 - 2\rho_{xy}\left(\frac{x-\mu_x}{\sqrt{\sigma_{xx}}}\right)\left(\frac{y-\mu_y}{\sqrt{\sigma_{yy}}}\right)\right]\right\} dx\ dy$$

Using Gauss-Legendre Quadrature method (Atkinson, 1989),

$$C_{ij} \approx \frac{x_{i+1} - x_i}{2} \frac{y_{j+1} - y_j}{2} \left[\sum_{k=1}^{n} \sum_{K=1}^{n} f\left(\frac{x_{i+1} + x_i}{2} + \frac{x_{i+1} - x_i}{2} z_k,\ \frac{y_{j+1} + y_j}{2} + \frac{y_{j+1} - y_j}{2} z_K \right) \omega_k \omega_K \right]$$

$$Cij = \int_{x_{i-1}}^{x_i} \int_{y_{j-1}}^{y_j} \left[\sum_{l=1}^{n} \sum_{k=1}^{n} f\left(\frac{x_{i+1}+x_i}{2} + \frac{x_{i+1}-x_i}{2} z_l, \frac{y_{j+1}+y_j}{2} + \frac{y_{j+1}-y_j}{2} z_k \right) \omega_l \omega_k \right]$$

the probability of each cell was calculated by computer. Then the expected frequency for each cell was found by multiplying the total number of sample subjects to the probability of each cell. Having fined observed and expected frequencies the chi-square tests were employed to test the likelihood of the sample distribution.

RESULTS

The number of observations, means, standard deviations, minimum, and maximum values of the four Project TALENT subtests and the two composites are listed in Table 2. The scores of the four subtests are all numbers of correct answer and the scores of the two composites are Z scores.

Table 2 Numbers, means, standard deviations, minimum and maximum values of four tests and two composites

	N	MEAN	STD	MIN	MAX
Disguised Words	3908	14.51	6.99	0	30
Spelling	3910	9.21	3.03	0	16
Visualization in 2-D	3905	12.59	5.79	0	24
Visualization in 3-D	3898	8.44	3.16	0	16
Phonological Coding	3903	0.00	0.87	-2.72	2.58
Image Coding	3892	0.00	0.86	-2.49	2.33

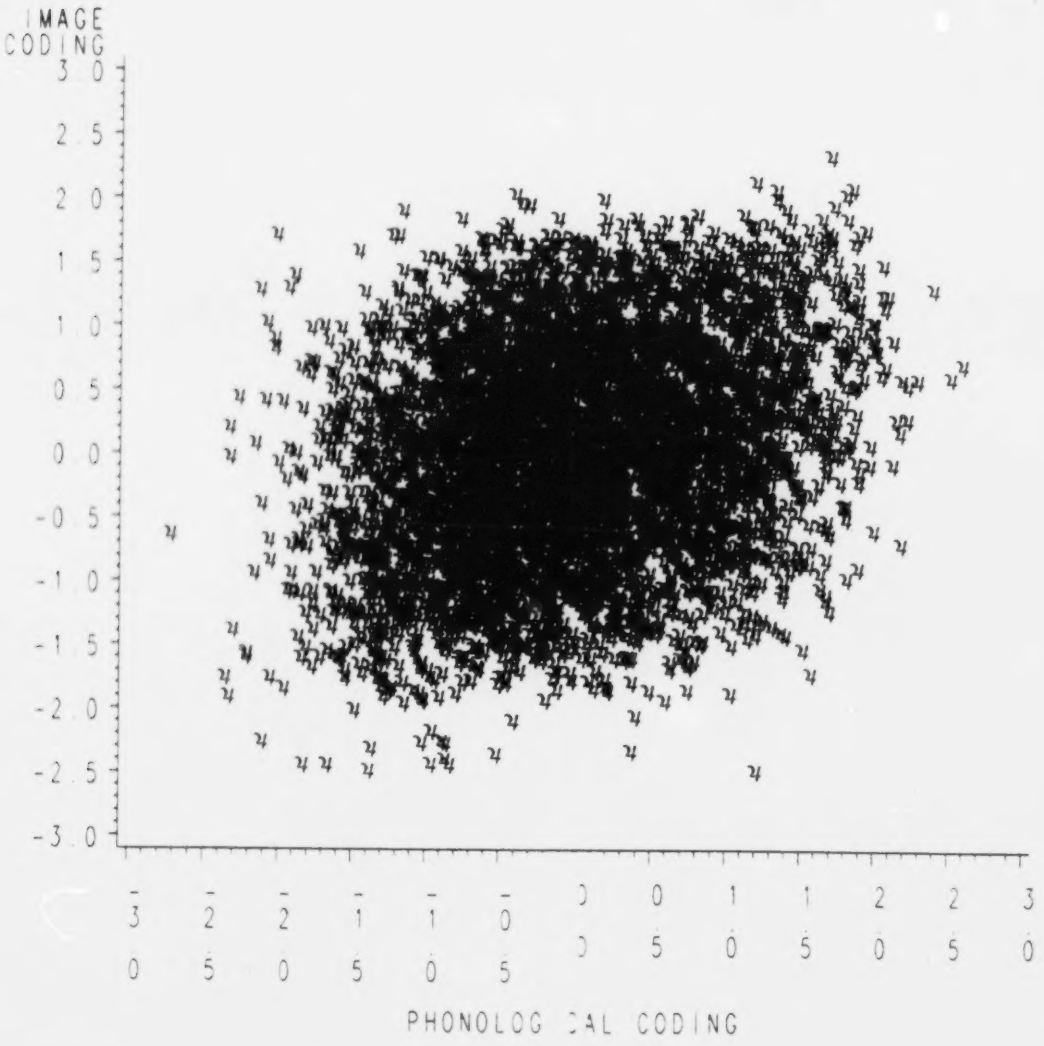
Table 3 gives intercorrelations between four tests and two composites. The tests defined as same coding ability show at least moderate correlations, whereas the correlation coefficients between the tests defined as different coding ability are low. This evidence indicated that four tests of Project TALENT file serves my research purpose well. As defined

above, phonological and image coding ability treat different type of information, thus, the correlation between them should be low.

Table 3 Intercorrelation between four tests and the two composites

	2	3	4	5	6
1. Disguised Words	.532	.297	.272	.815	.309
2. Spelling		.125	.166	.844	.141
3. Visualization in 2-D			.485	.231	.858
4. Visualization in 3-D				.222	.851
5. Phonological Composite					.266
6. Image Composite					

A scatterplot of the phonological coding composite and image coding composite scores of whole sample is shown in graph 4. The appearance of this plot looks like Graph 3.



Graph 4 Scatterplot of phonological and image coding composites scores (Project TALENT data)

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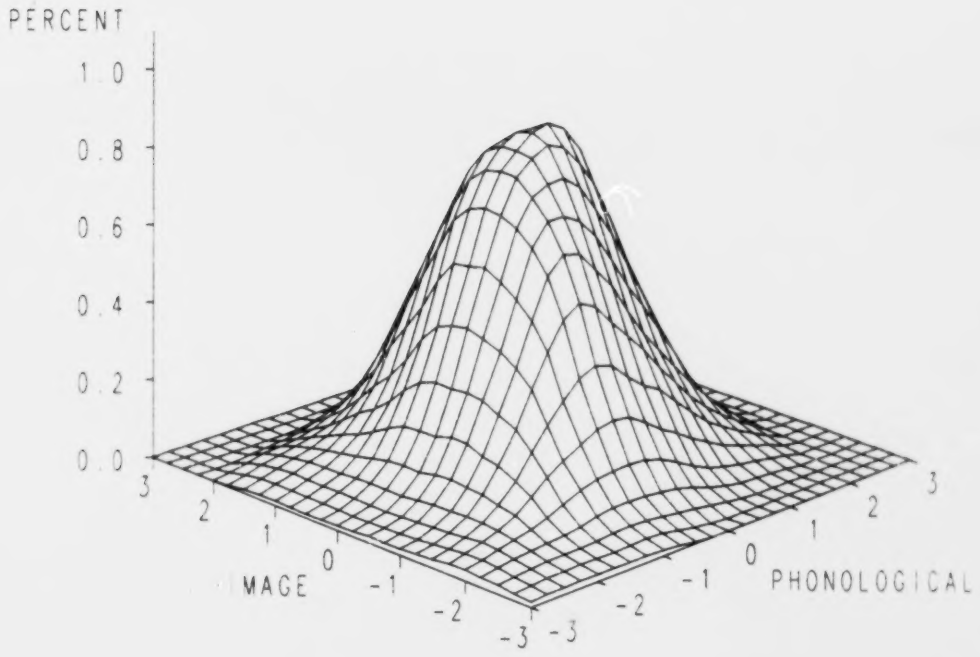
A 3-D plot for the distribution of phonological and image coding composites is exhibited in Graph 5. The unit of horizontal axises[2] is standard deviation whereas the unit for vertical axis is the cell percentage. The bivariate frequency distribution of this model has a bell-shaped look.



Graph 5 Three dimensional plot for phonological and image coding composites

To test bivariate normal hypothesis, each composite were cut into six parts by its standard deviation to make a 6*6 table. Namely, the phonological coding composite was

2. The range of horozontal axises in the 3-D plot is 6 standard deviations (from -3 to 3 SD). The cell width is 0.25 SD. Thus, the 3-D plot has 576 cells.

Table 5 Cell frequencies of observed and expected bivariate distributions for Phonological and Image Coding composites.

IMAGE CODING	PHONOLOGICAL CODING												SUM	
			(-2)-(-1)		(-1)-0		0-1		1-2		>2			
	obs	exp	obs	exp	obs	exp	obs	exp	obs	exp	obs	exp	OBS	EXP
>2	0	0	1	4	7	19	11	35	17	24	4	7	40	89
1-2	7	4	50	37	197	143	241	205	147	111	27	24	669	524
0-1	13	19	154	143	413	430	412	485	221	205	32	35	1245	1317
(-1)-0	19	35	199	205	444	485	406	430	161	143	12	19	1241	1317
(-1)-(-2)	17	24	138	111	244	205	154	143	46	37	2	4	601	524
<-2	6	7	27	24	16	35	11	19	3	4	0	0	63	89
SUM	62	89	569	528	1321	1326	1235	1326	595	528	77	89	3859	3860

Note: Scale unit is standard deviation, and the correlation between the two variables is 0.266.

divided by 0.87, whereas the image coding composite was divided by 0.86. Using computer statistical program, the observed frequencies for each cell were easy to find. The expected percentages for 36 cells of the bivariate normal distribution were obtained using the Gauss-Legendre Quadrature method on bivariate normal density function with mean equal to zero, and standard deviation equal to one, and the correlation between the two composites equal to 0.266 (Shown in Table 4). Then, the cell percentages were multiplied by total number of 3859 to get cell frequencies. Both observed and expected frequencies are put into Table 5 with horizontal dimension as phonological coding ability, and the vertical as image coding ability.

We may think that the 36 cells of the Table 5 is composed of three circles. The largest one is formed by the cells in the extreme ends, namely, greater than 2 SD, or less than -2 SD. The total cell number of this circle is 20. The second circle is made of the cells in one to two, or negative one to negative two standard deviation. The total cell number of this circle is 12. The third circle is composed of the four central cells. The interesting finding of this table is that almost all cell observed frequencies in the first and third circles are less than expected frequencies, and the cell observed frequencies in the second circle are all more than expected frequencies. It seems to suggest that people with mild unbalanced coding ability patterns tend to occur more frequently than they are expected, and people with seriously unbalanced coding ability patterns tend to occur less frequently than predicted.

The same results could be found when we look at only the four corners of the table as intellectual exceptionalities. If the cut-off scores are set at two standard deviations from mean, the observed frequencies in up-right and low-left corner are all less than expected one. No observed or expected case appears in up-left or low right cells. However, while setting cut-off scores in one standard deviation from mean, the situation would be changed. After adding observed and expected frequencies in four cells of each corner, we can find that the observed frequencies of all types of exceptionality are more than expected frequencies. For the four cells in up-right corner, the observed frequency is 185, the expected frequency is 166; for the low-left corner the observed frequency is 188, and the expected frequency is 166 again. For the up-left and low-right corner the expected frequencies is 45, the observed frequency of the former is 58, and of the later is 51.

The other finding is that people with relative balanced encoding pattern are much more common than people with relative uneven encoding patterns. If we regard the cell along the diagonal (from low-left to up-right, within the dashed lines) of Table 5 as relative

Table 6 Cell percentage of observed and expected bivariate distribution for Phonological and Image Coding composites

IMAGE CODING	PHONOLOGICAL CODING												SUM	
	<-2		(-2)-(-1)		(-1)-0		0-1		1-2		>2			
	obs	exp	obs	exp	obs	exp	obs	exp	obs	exp	obs	exp	OBS	EXP
>2	.00	.01	.00	.10	.03	.48	.00	.895	.13	.62	.00	.18	.15	2.285
1-2	.08	.10	.64	.97	4.17	3.71	5.12	5.32	3.14	2.89	.13	.62	13.28	13.59
0-1	.15	.48	3.40	3.71	13.46	11.15	13.90	12.57	5.87	5.32	.33	.895	37.12	34.125
(-1)-0	.18	.895	4.76	5.32	14.39	12.57	12.25	11.15	3.78	3.71	.05	.48	35.42	34.125
(-1)-(-2)	.15	.62	3.24	2.87	5.87	5.32	3.58	3.71	.72	.97	.00	.10	13.56	13.59
<-2	.03	.18	.15	.62	.21	.895	.05	.48	.03	.10	.00	.01	.46	2.285
SUM	.59	2.285	12.20	13.59	38.12	34.125	34.90	34.125	13.67	13.59	.51	2.285	100.00	100.00

Note: Scale unit is standard deviation, and the correlation between the two variables is 0.266.

balanced encoding pattern, the total number of subjects in this region is 2963. It is 77% of the sample population. Theoretical speaking, because the correlation coefficient between the two composites is 0.266, the scatterplot of the two composites is an ellipse. Thus more cases stand along the main axis than the minor axis. Moreover, from Graph 5 we can see the distribution of the this bivariate model is bell-shaped. This means more cases are concentrated in the central part. The total cases of the four central cells (or the third circle) is 1675, which is 43% of the sample. These individuals hold a balanced information encoding ability pattern.

Table 6 contains observed and expected percentages for 36 cells, accumulative row percentages and column percentages. From this table, we can have a more clear picture about each parts of the bivariate model, compare to bivariate normal distribution. One notable feature of this model is that the density decrease from center to edge. Averaging cell percentage for each circle, the mean percentage for third circle(four central cells) is 10.85; mean percentage of the second circle is 4.22; and the mean of the first circle is 0.30. This feature is similar to bivariate normal density function.

The chi-square values of cell observed and expected comparison, row sum, column sum and the sum total are shown in Table 7. The formula for sum total chi-square value is:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} \frac{(f_o - f_e)^2}{f_e}$$

Here, f_o stands for the cell observed frequency, and f_e stands for the cell expected frequency. They are all listed in Table 5. The sum total of chi-square value for the two composites is 142.74. The degree of freedom in this likelihood test is 35. The critical value for df=35 and α=0.005 is 60.26. The sum total chi-square value in the Table 7 is grater than the critical value. Thus the null hypothesis is rejected. We could say the bivariate distribution of two information encoding abilities did not distributed normally.

Descriptive statistics of phonological and image coding composites using Project TALENT public use data seems support the bivariate model. From this data we do find some people have high abilities in both phonological and image coding; some have lower abilities in both; some have unbalanced ability patterns with high ability in one, and low ability in the other;

Table 7 Chi-square values for comparison of observed and expected frequencies within each cell

IMAGE	PHONOLOGICAL						
	<-2	(-2)-(-1)	(-1)-0	0-1	1-2	>2	SUM
>2	0.00	2.25	7.58	16.45	2.04	1.29	29.61
1-2	2.25	4.57	20.39	6.32	11.67	0.37	45.57
0-1	1.89	0.85	0.67	10.98	1.25	0.26	15.90
(-1)-0	7.31	0.18	3.46	1.34	2.27	2.58	17.14
(-2)-(-1)	2.04	6.58	7.42	0.85	2.19	1.00	20.08
<-2	0.14	0.37	10.31	3.37	0.25	0.00	14.44
SUM	13.63	14.80	49.83	39.31	19.67	5.50	142.74

and most people have balanced middle level encoding abilities in both. Graph 4 gives a clear picture about range of the two composites in a two dimension space. This graph looks similar to Graph 3, the graph of bivariate model. Although bivariate normal hypothesis is rejected, we did find some properties of this model which are close to bivariate normal distribution. First the density of the distribution decreases from center to edge. Second, the appearance of the bivariate frequency distribution is a bell-shape distribution which looks similar to bivariate normal distribution. Graph 5 gave a clear demonstration. In this study, sample size is quite large. After deleting missing data, there were still 3859 subjects which gave the study strong power to reject null hypothesis. For all these reasons, I suggest the use of bivariate normal distribution as a convenient way to roughly estimate the populations of each kind intellectual exceptionality.

DISCUSSION

The model has its advantages. First, the model suggests an continuous intellectual entity at the information encoding level for the entire population. The model links all kinds of intellectual exceptionalities together with normal people, and gives a clear picture about the

location of each specific group. It is convenient to apply a bivariate normal distribution to roughly estimate the population of each exceptional group. Using psychometric definitions of intellectual exceptionalities to set cut-off scores, the frequencies of each specific group could be found. Second, for a long time, specific giftedness has been a mystery to us. People cannot understand or do not believe that eminent or clever people have had great learning difficulties. Now, from the model, we can see there are individuals with unbalanced ability patterns. They may be a great talent in one type of abilities, but weak in the other, although the number of this kind of giftedness is small.

Evidence from biographies of eminent people, such as Einstein, Faraday, Churchill, Da Vinci and many others, supports this model. A common character of these eminent people is that their powerful visual imaginations came at a cost (West, 1990). Most of them had weaknesses in memory for words, numbers and texts (like Einstein and Faraday), had problems of spelling, dictionary checking (like Churchill and Da Vinci) or even language itself (Nadia). All these weaknesses seems to be related to sequential, or phonological coding ability.

Recent studies on language learning of phonological deficits reveal the phonological long-term learning is a separate mental process to operation of language skills. The impairment of phonological memory may have disastrous consequences for learning new words, but not for learning new verbal task with learned vocabulary (Baddeley, Papagno & Vallar, 1988). Thus, phonological component of working memory seems crucial to the acquisition of language abilities in children, especially, the children in elementary school and lower secondary, not in adults who have fully developed their language skills. Moreover, if trade-off between the two coding abilities is true, it is possible that the children with phonologicial disability but above normal general ability, to develop high image coding ability and accumulate more propositionally coded spatial knowledge, and then, become a high spatial eminent people. In this way, we could say that the model is useful for understanding of people with unbalanced ability patterns and may give new theory to special giftedness. Then, hopefully, the new theory may contribute to the development of new psychological instruments for diagnosis, as well as special gifted education.

In past decade, research on early neurological growth pattern (Geschwind, 1985) and the microscopic structure of the brain (Springer & Deutsch, 1981; Brownell et al., 1984) has provided the beginning of solid evidence about the brain differences. The uneven

information encoding ability patterns is related to the different brain structures (West, 1991).

The disadvantages of this model may be three. First, it explores only information encoding process. Other information processes, such as problem-solving, or metacognition are not discussed here. At the information encoding level two dominant information perceive types were found through literature review, and they are relatively independent to each other. Whereas at higher information processing level all kinds of abilities are highly correlated with G. Secondly, the model deals only with three main coding abilities, two perceptual coding abilities and the abstract coding ability, which may eliminate other perceptual coding abilities. Although information encoding is the essential first step of human information processing, and higher level abilities are built on this elementary level ability, human abilities are developed with education and experiences. This model is useful for understanding different ability pattern, but, is not sufficient for judging giftedness.

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